



(51) International Patent Classification:

B60L 11/00 (2006.01) **H05K 7/02** (2006.01)
H05K 9/00 (2006.01) **H05K 5/04** (2006.01)

(21) International Application Number:

PCT/US2012/057497

(22) International Filing Date:

27 September 2012 (27.09.2012)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

13/252,306 4 October 2011 (04.10.2011)

US

(71) Applicant: **HITACHI, LTD** [JP/JP]; 6-6 Marunouchi 1-chome, Tokyo, 100-8280 (JP).

(72) Inventors; and

(71) Applicants : **ZENG, Hua** [CN/US]; C/o Hitachi America, Ltd. Research &, Development Division, 34500 Grand River Ave., Farmington Hills, MI 48335 (US). **TAKAHASHI, Masayoshi** [JP/JP]; C/o Hitachi America, Ltd. Research &, Development Division, 34500 Grand River Ave., Farmington Hills, MI 48335 (US).

(74) Agents: **SPRINKLE, Douglas, W** et al.; Gifford, Krass, Sprinkle, Anderson & Citkowski, P.C., 2701 Troy Center Drive, Suite 330, Post Office Box 7021, Troy, MI 48007-7021 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

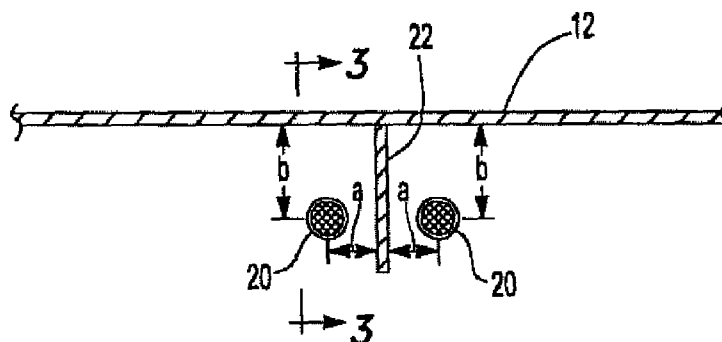
Declarations under Rule 4.17:

— of inventorship (Rule 4.17(iv))

Published:

— with international search report (Art. 21(3))

(54) Title: SYSTEM FOR POWER TRANSMISSION



(57) Abstract: A system for reducing electromagnetic noise generated by common mode currents in electrical connections of a power inverter and battery in an electric or hybrid electric vehicle. A pair of spaced apart electrical conductors extends along the vehicle chassis and electrically connects the power inverter to the battery. An electrically conductive metal plate is positioned between the spaced apart electrical conductors. This metal plate is electrically connected to the chassis adjacent at least both of the power inverter and the battery/motor. Besides this, more connecting points are required to keep the distance between two points less than half wavelength of the maximum frequency of EMI requirements, and most preferably this metal plate is electrically connected to the chassis all the way with infinite connecting points. The metal plate is positioned so that the metal plate is closer to the electrical conductors than the space in between the electrical conductors and the vehicle chassis.



SYSTEM FOR POWER TRANSMISSION

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of U.S. Patent Application 13/252,306 filed October 4, 2011, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

I. FIELD OF THE INVENTION

[0002] The present invention relates generally to a power transmission system with reduced electromagnetic interference and, more particularly, to the power transmission between a power inverter and a battery in an electric or hybrid electric automotive vehicle.

II. DESCRIPTION OF RELATED ART

[0003] New developments and advancements in the automotive industry are primarily driven by new and improved electronic components in the automotive vehicles. These new developments include, for example, vehicle navigation systems, infotainment equipment, safety equipment, and the like.

[0004] In order to ensure the functionality of the increasingly complex electronic systems in automotive vehicles and also to minimize the negative impacts of the automotive system on external systems, electromagnetic capability (EMC) has become an increasing concern for the automotive vehicles. This is particularly true in hybrid electric vehicles and electric vehicles where high voltage and high current switching is required in order to power the vehicle.

[0005] In particular, hybrid electric vehicles and electric vehicles (hereinafter collectively referred to as "electric vehicles") typically use a power inverter which switches high current and voltage and provides the necessary power outputs to the electric motor or motors utilized to propel the vehicle. In order to supply the electrical power to the power inverter for ultimate distribution to the electric vehicle motor or motors, the electric vehicle includes a high capacity electric battery.

[0006] Conventionally, a pair of elongated conductors is used to electrically connect the battery to the power inverter in an electric vehicle. The electric battery is

usually spaced from the power inverter so that the electrical conductors between the power inverter and the battery extend along the electrically conductive vehicle chassis.

[0007] Due to impedance mismatching of the electrical conductors and their connection with both the power inverter and the battery, common mode electric currents are generated along both conductors. These common mode electric currents, in turn, generate electromagnetic interference (EMI) which may interfere with the electrical components of the vehicle electrical system. For example, the common mode electrical currents generated on the electrical conductors between the power inverter and the battery are known to generate electrical noise which interferes with the electrical system of other electrical components of the vehicle, such as the radio or other infotainment device. As such, the reduction of electrical noise from these common mode currents has become a high priority in the design of electrical systems for automotive vehicles and especially electric vehicles where the generation of EMI is inherently more challenging than nonelectric automotive vehicles.

SUMMARY OF THE PRESENT INVENTION

[0008] The present invention provides a system for reducing electromagnetic noise generated by common mode currents in the electrical connection of a spaced apart power source and load such as the battery and inverter in an electric automotive vehicle.

[0009] The system includes a pair of spaced apart electrical conductors. These electrical conductors extend along the vehicle chassis between the power source and load or the battery and the power inverter. The electrical conductors are electrically connected to both the power source and the load thus electrically connecting them together. Furthermore, the power source and load may comprise the battery and power inverter in the electric vehicle.

[0010] An electrically conductive metal plate is positioned in between the spaced apart electrical conductors. This metal plate is electrically connected to the vehicle chassis at least at both the power source and the load. Besides this, more connecting points are required to keep the distance between two points less than half wavelength of the maximum frequency of EMI requirements, and most preferably this metal plate is electrically connected to the chassis all the way with infinite connecting points.

Furthermore, the conductors are arranged so that the spacing between the conductors and the metal plate is less than the spacing between the conductors and the vehicle chassis. Conductors are symmetrically distributed on two sides of the metal plate. In doing so, the return current is changed from the chassis to the metal plate, and two
5 current loops made by each electrical conductor and metal plate can generate opposite magnetic fields, therefore they are cancelled by each other, thus reducing the total electromagnetic interference.

BRIEF DESCRIPTION OF THE DRAWING

[0011] A better understanding of the present invention will be had upon reference
10 to the following detailed description when read in conjunction with the accompanying drawing, wherein like reference characters refer to like parts throughout the several views, and in which:

[0012] FIG. 1 is a diagrammatic view illustrating an electric vehicle;

[0013] FIG. 2 is a diagrammatic sectional view taken along line 2-2 in FIG. 1 and
15 enlarged for clarity;

[0014] FIG. 3A is a diagrammatic side view illustrating a preferred embodiment of the present invention;

[0015] FIG. 3B is a view similar to FIG. 3A, but illustrating a modification;

[0016] FIG. 4 is a graph illustrating the EMI reduction in accordance with the
20 present invention;

[0017] FIGS. 5A and 5B are other examples of embodiments of the invention with 3-phase motor cables; and

[0018] FIG. 6 is the diagrammatic sectional view taken along line 2-2 in FIG. 1 but for conventional cable routing without the metal plate.

25 [0019] FIG. 7 is a diagrammatic view illustrating an electric train;

[0020] FIG. 8 is a structure of Main convertor described in FIG. 7;

[0021] FIG. 9 is a diagrammatic sectional view taken along line 4-4 in FIG 7 and enlarged for clarity; and

[0022] FIG. 10 is another example of embodiments of the invention with 3-phase
30 motor cables.

DETAILED DESCRIPTION OF A PREFERRED
EMBODIMENT OF THE PRESENT INVENTION

[0023] With reference first to FIG. 1, an electric automotive vehicle 10 is illustrated diagrammatically. In a conventional fashion, the automotive vehicle 10 includes a chassis 12 constructed of an electrically conductive material, such as steel. That automotive chassis 12, furthermore, forms the ground plane for the automotive vehicle.

[0024] A battery 14 is contained in or supported by the chassis 12. Similarly, a power inverter 16 is contained within or supported by the chassis 12. The power inverter 16 provides electrical power to an electric motor 18 which is drivingly connected to one or more of the vehicle wheels.

[0025] With reference now to FIGS. 1 and 2, a pair of spaced apart electrical conductors 20 extends along the vehicle chassis 12 and electrically connects the battery 14 to the power inverter 16. Any conventional means may be utilized to electrically connect the conductors 20 to both the power inverter 16 and the battery 14 with reference to FIG. 6.

[0026] As best shown in FIG. 2, the electrical conductors 20 are spaced apart and generally parallel to each other in their extent from the battery 14 to the power inverter 16. Furthermore, the conductors 20 are spaced from the chassis 12 by a distance b .

[0027] Since it is extremely difficult, if not altogether impossible, to obtain a perfect impedance match between the electrical connections of the electrical conductors 20 and the battery 14 and power inverter 16, common mode currents will inherently occur along the conductors 20 during the operation of the electric vehicle 10. It is these common mode currents which result in EMI and potential interference with the other electronic and electrical systems of the automotive vehicle 10.

[0028] In order to reduce the generation of EMI by the common mode currents, a generally planar metal plate 22 constructed of an electrically conductive material is positioned in between the electrical conductors 20, with reference to FIG. 2. This metal plate 22, furthermore, is preferably positioned so that the electrical conductors 20 are spaced apart from the metal plate by an equal distance a . The distance a , furthermore, is preferably less than the distance b so that the electromagnetic field generated by common mode currents in the conductors 20 will induce more current

flow in the metal plate 22 than in the chassis 12. The center of common mode current induced on the cables will overlap the center of the return current in the metal plate 22, the electromagnetic fields generated by the ongoing common mode currents on the cables 20 will cancel the fields generated by the return currents on the metal plate 22 and significantly reduce the noise.

[0029] With reference to FIG. 3A, the most preferable configuration is to electrically connect the metal plate to the chassis all the way. If only finite connecting points are allowed between the metal plate and chassis, this metal plate is electrically connected to the vehicle chassis at least at both the power source and the load as shown in FIG. 3B. Besides this, more connecting points are required to keep the distance between two points less than half wavelength of the maximum frequency of EMI requirements to avoid resonance of the metal plate.

[0030] As best shown in FIG. 4, the electric metal plate 22 is electrically connected to the chassis 12. By thus the return path of the common mode current is changed from the chassis 12 to the metal plate 22. Thus, in turn, two current loops made by each electrical conductor and metal plate can generate opposite magnetic fields, therefore they are cancelled by each other, thus reducing the total electromagnetic interference.

[0031] With reference now to FIG. 4, a graph illustrating the effect of the metal plate 22 is illustrated as a function of noise on the Y axis versus frequency on the X axis. Graph 30 illustrates the generation of noise for the conventional prior art vehicles, i.e. vehicles without the metal plate 22. Graph 32 illustrates noise as a function of frequency with the metal plate installed but where the distance a is greater than the distance b.

[0032] Similarly, graph 34 illustrates the generation of noise as a function of frequency where the distance a equals the distance b while graph 36 illustrates the generation of noise as a function of frequency where the distance a is less than the distance b.

[0033] As becomes clear from the graphs 30-36 illustrated in FIG. 4, the provision of the metal plate 22 and with the distance a, i.e. the spacing between the conductors and the metal plate 22 being less than the spacing b, i.e. the distance

between the conductors 20 and chassis 12, provides the greatest reduction of EMI for the vehicle. Indeed, this reduction is as high as 14 dB as shown at 38.

[0034] Through [0027], we described the idea for high voltage DC cable. The same idea can be applied to 3-phase AC cables with reference to FIG. 6. Metal plate is needed to be placed between cables as shown in FIGS. 5A and 5B. These common mode currents induced on the cables 20 will return through the metal plate 22, and electromagnetic fields generated by these ongoing common mode currents on the cables and return currents on the metal plate 22 will cancel each other and significantly reduce the noise.

[0035] As shown above, we described the idea for high voltage DC cable, it can be seen that the present invention provides a simple, yet effective, means for reducing EMI in an electric automotive vehicle. Having described our invention, however, many modifications thereto will become apparent to those skilled in the art to which it pertains without deviation from the spirit of the invention as defined by the scope of the appended claims.

[0036] From the foregoing, it can be seen that the present invention provides a simple, yet effective, means for reducing EMI in an electric automotive vehicle. This invention can also be applied on other vehicle types like construction machine, train, and etc. FIG. 7 gives another embodiment with a train configuration. FIG. 8 describes how converter, inverter and motor are connected together. The common mode currents are generated on HVDC cables between converter and inverter and motor cables between inverter and motors. The invention can be applied on HVDC cables and motor cables to reduce the EMI effects of these common mode currents. It can be realized as shown in FIG. 2 for HVDC cables or as shown in FIG. 5 for motor cables.

As described above, many modifications will also be available here.

[0037] When the metal tubes are used to enclose these cables, the metal tubes can be slightly modified as shown in FIG. 9 for HVDC cables and FIG. 10 for 3-phase motor cables. The distance a, furthermore, is preferably less than the distance b, c or d so that more the common mode currents in the conductors 20 will return along the metal plate 22 than along the chassis 12 or case 23. Therefore the electromagnetic fields generated by the currents on the motor cables will cancel the fields generated by the return currents on the metal plate, and reduce the total radiated fields.

[0038] Additionally, if serious common mode currents are induced on power lines for auxiliaries, along with large loop area of these cables as shown in FIG. 7, which will cause severe EMI problem. The invention can also be used on these auxiliary power lines to reduce the EMI coupling.

5 [0039] We claim:

CLAIMS

1. An electrical power transmission system for transmitting power between a power source and a load spaced from the power source, said power source and said load mounted in a housing, said system comprising:

5 a pair of spaced apart electrical conductors extending along the housing between and electrically connecting the power source to the load,

an electrically conductive metal plate positioned between said spaced apart electrical conductors, said metal plate being electrically connected to the housing adjacent at least both ends of the metal plate between the power source and the load with connecting points whose distance is less than the half of the smallest wavelength among interested frequencies.

2. The system as defined in claim 1 wherein said metal plate is electrically connected to said housing continuously along its length with infinite connecting points.

3. The system as defined in claim 1 wherein the housing comprises a chassis of an automotive vehicle.

4. The system as defined in claim 3 wherein the automotive vehicle comprises an electric vehicle or a hybrid electric vehicle.

5. The system as defined in claim 4 wherein the load comprises a power inverter and the power source comprises a storage battery.

6. The system as defined in claim 1 wherein said electrical connectors are spaced from the housing by a distance greater than the spacing between said electrical conductors and said metal plate.

7. The system as defined in claim 6 wherein said electrical conductors are equidistantly spaced from said metal plate.

8. The system as defined in claim 1 wherein said metal plate is planar in shape.

9. A system for reducing electromagnetic noise generated by common mode currents in the electrical connection of a spaced apart power inverter and battery/motor in an electric or hybrid electric automotive vehicle having an electrically conductive chassis, said system comprising:

a pair of spaced apart electrical conductors extending along the chassis between and electrically connecting the power inverter to the battery/motor,

an electrically conductive metal plate positioned between said spaced apart electrical conductors, said metal plate being electrically connected to the chassis adjacent at least both ends of the metal plate between the power inverter and the battery/motor,

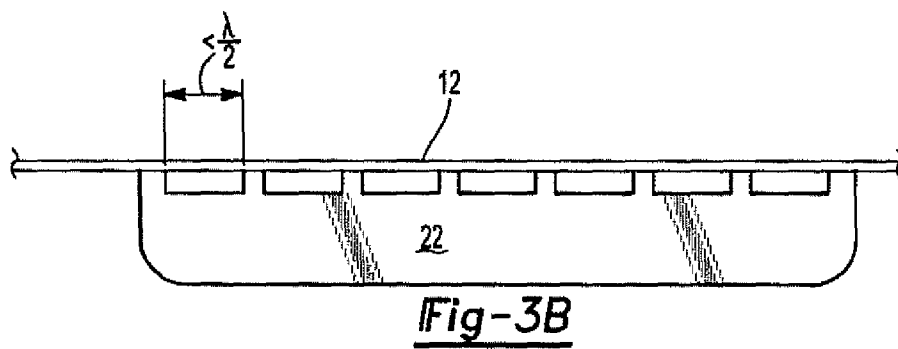
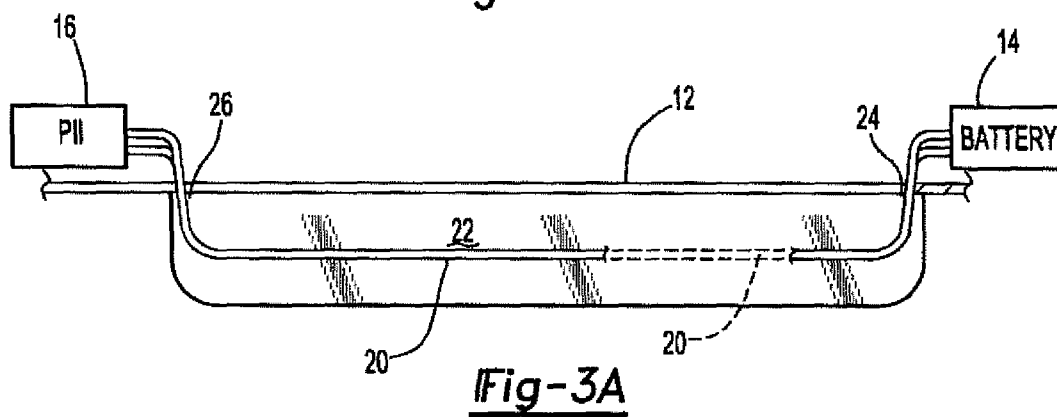
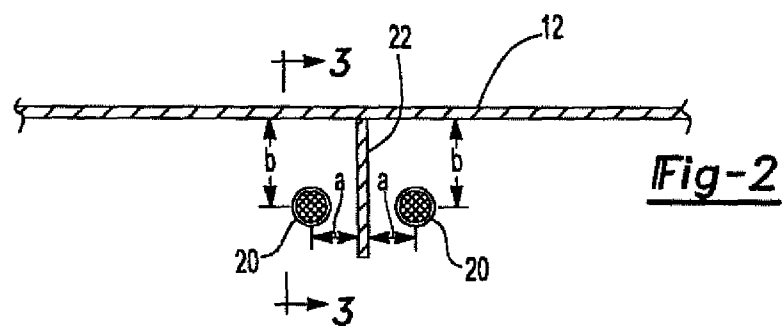
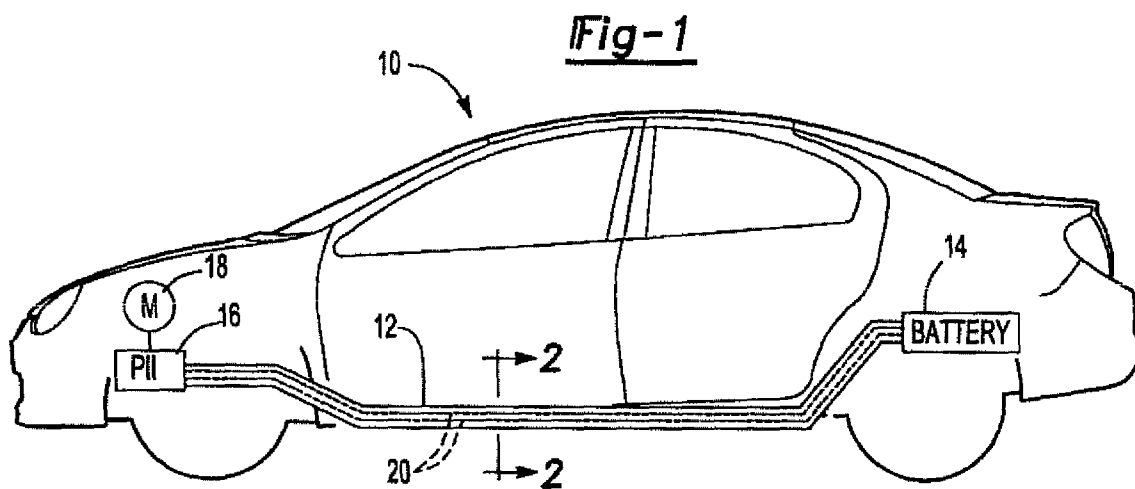
an electrically conductive metal plate positioned between said spaced apart electrical conductors, said metal plate being electrically connected to the chassis between the power inverter and the battery/motor with finite connecting points whose distance is less than the half of the smallest wavelength among interested frequencies.

10. The system as defined in claim 9 wherein said metal plate is electrically connected to said chassis all the way with infinite connecting points.

11. The system as defined in claim 9 wherein said electrical connectors are spaced from the chassis by a distance greater than the spacing between said electrical conductors and said metal plate.

12. The system as defined in claim 11 wherein said electrical conductors are equidistantly spaced from said metal plate.

13. The system as defined in claim 9 wherein said metal plate is planar in shape.



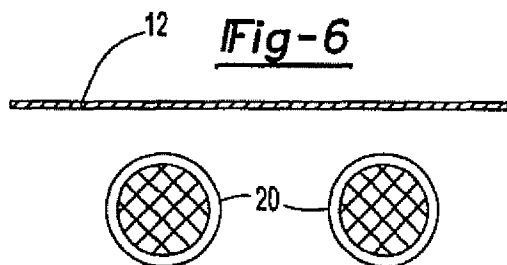
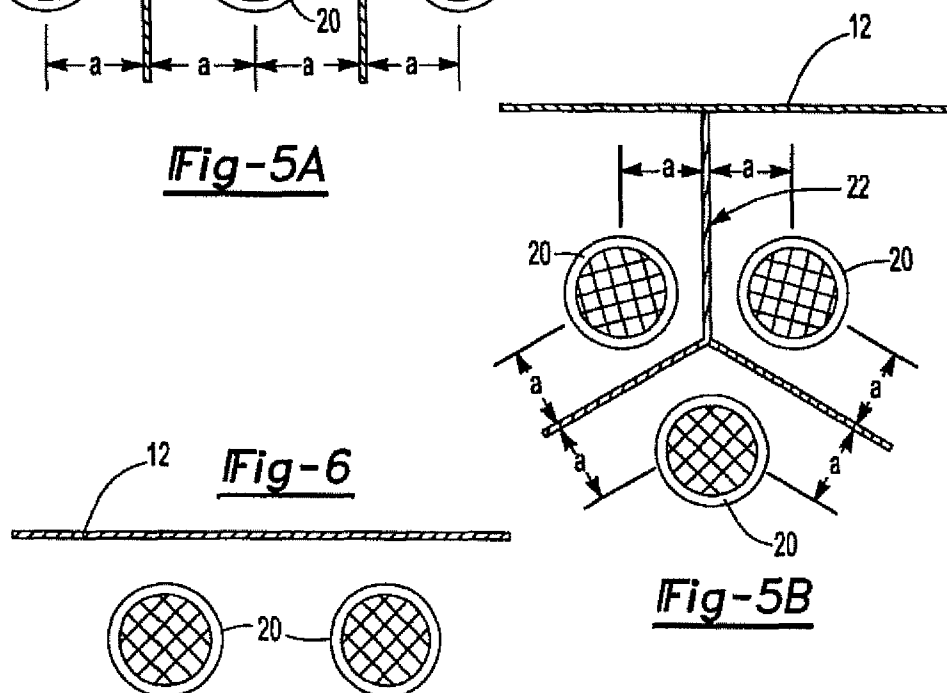
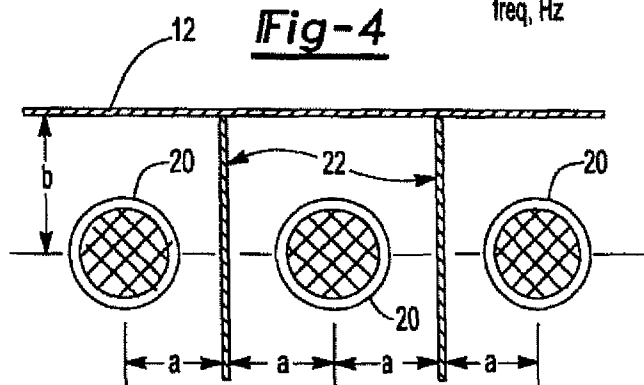
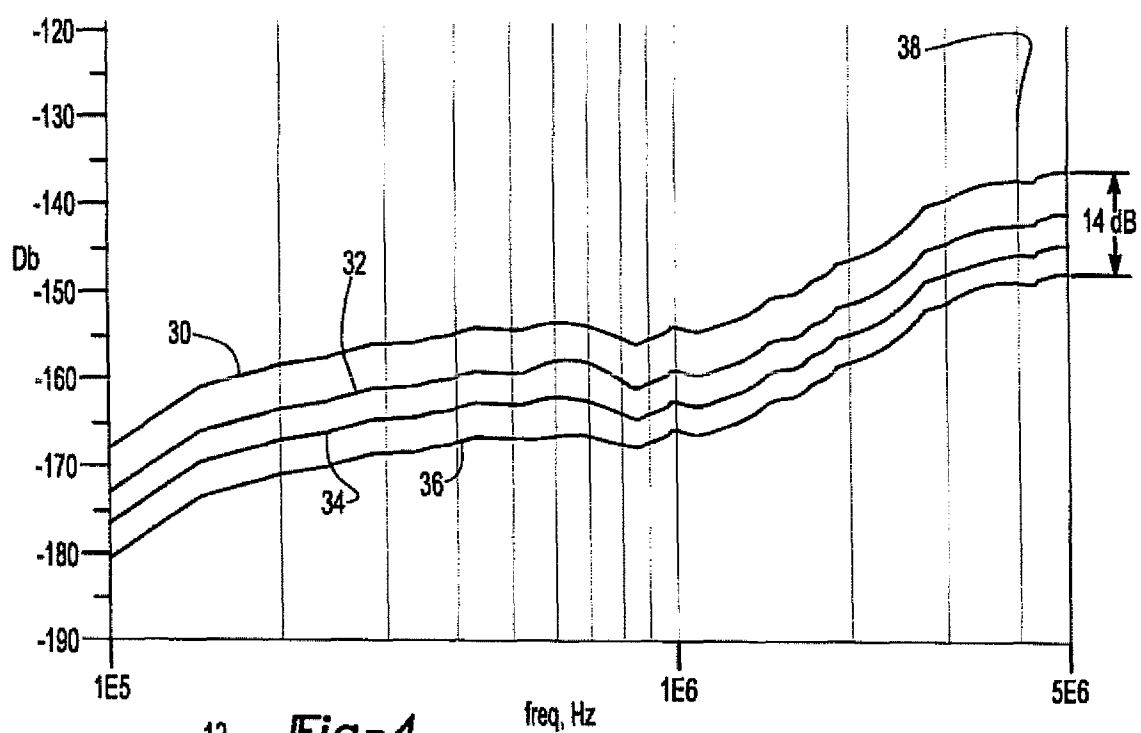
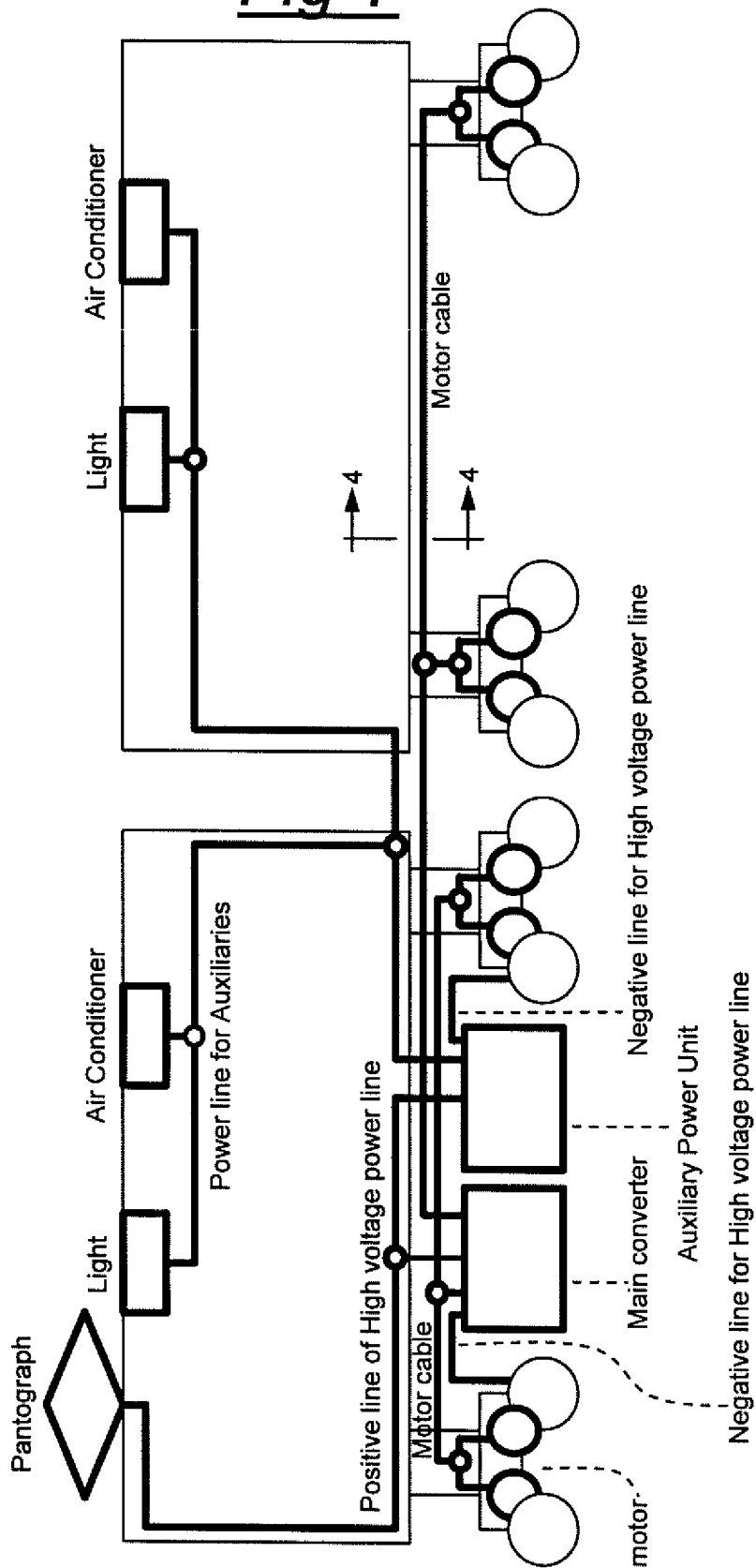
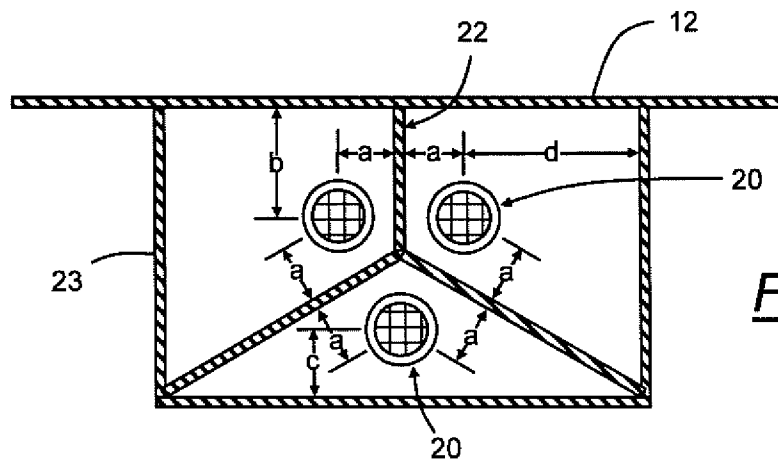
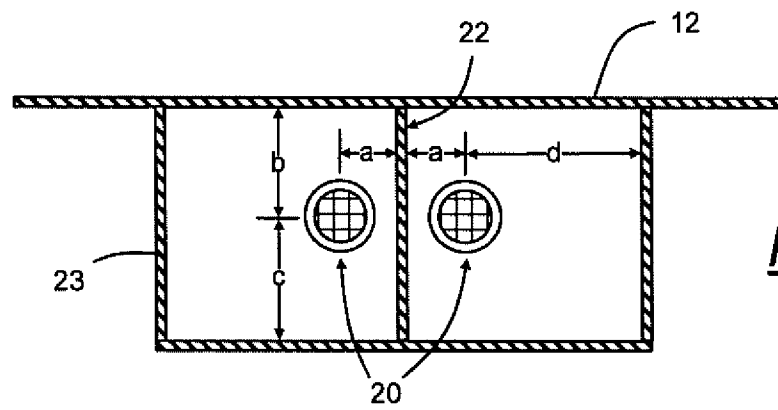
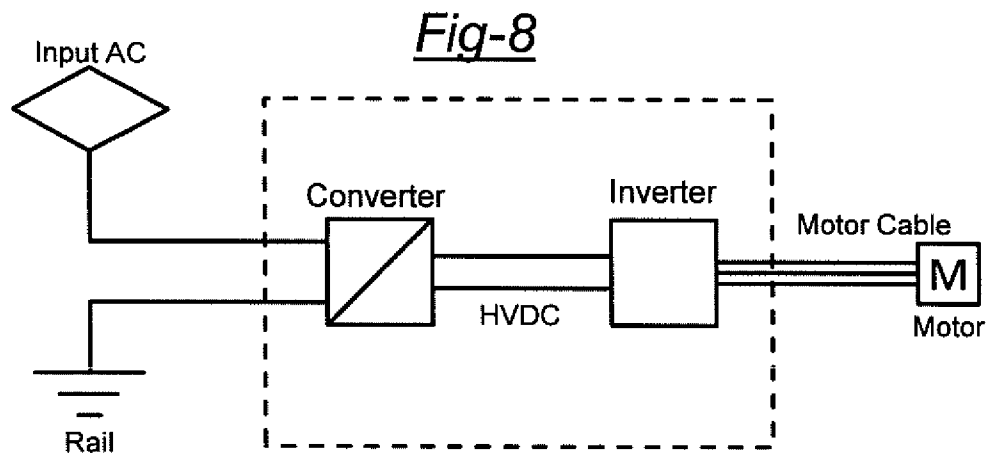


Fig-7





INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2012/057497

A. CLASSIFICATION OF SUBJECT MATTER

*B60L 11/00 (2006.01)**H05K 9/00 (2006.01)**H05K 7/02 (2006.01)**H05K 5/04 (2006.01)*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H05K 5/00-5/06, 7/00-7/20, 9/00, B60L 11/00-11/18, B60K 6/00-6/547, B60W 20/00, H02J 1/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PATSEARCH, ESP@CENET, RUPAT, DWPI, PAJ, USPTO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009/0107694 A1 (AUTONETWORKS TECHNOLOGIES LTD et al.) 30.04.2009, abstract, fig. 1	1-13
A	DE 102005054926 A1 (YAZAKI CORP.) 08.06.2006, abstract, fig. 1	1-13
A	JP 2006312409 A (AUTO NETWORK GIJUTSU KENKYUSHO et al.) 16.11.2006, abstract, fig. 1	1-13
A	2291067 C2 (KALMYKOV VLADIMIR ILICH) 10.01.2007, abstract	1-13



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

“E” earlier document but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

23 November 2012 (23.11.2012)

Date of mailing of the international search report

11 January 2013 (11.01.2013)

Name and mailing address of the ISA/ FIPS
Russia, 123995, Moscow, G-59, GSP-5,
Berezhkovskaya nab., 30-1

Facsimile No. +7 (499) 243-33-37

Authorized officer

K. Ampilov

Telephone No. (495) 531-64-81